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RESEARCH MEMORANDUM

FLIGHT INVESTIGATION OF THE HEAT REQUIREMENTS FOR ICE PREVENTION ON AIRCRAFT WINDSHIELDS

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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FLIGHT INVESTIGATION OF THE HEAT REQUIREMENTS FOR ICE PREVENTION ON AIRCRAFT WINDSHIELDS

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SUMMARY

A flight investigation was conducted to establish the heat requirements for ice prevention on aircraft windshields mounted on the forebody of an airplane at several angles with the thrust axis. Electrically heated windshields were used in this investigation to provide a means of accurately measuring heat input to the windshield. The investigation showed that: (1) by assuming a design condition of an ambient-air temperature of 0° F, a heat input of approximately 1300 Btu per hour per square foot would prevent ice formation at airspeeds up to 220 miles per hour and liquid-water content up to 0.30 gram per cubic meter; (2) as the angle of the windshield with the thrust axis was decreased from 60° to 45°, the heat required for ice prevention remained constant. However, the heat required for ice prevention when the angle was decreased to 30° was about 25 percent less than for angles of 60° and 45°.

INTRODUCTION

One part of the general investigation of the airplane ice-prevention program has been concerned with preserving vision through the aircraft windshield during flight in icing conditions. A previous investigation (reference 1) has shown that the use of heat is a practical means of preventing ice formation on the aircraft windshield and has indicated the approximate quantity of heat required for windshield-ice prevention for one type of airplane.

An investigation has been conducted at the NACA Cleveland laboratory in order to establish more adequate data on the quantity of heat required for windshield-ice prevention. The data obtained in this investigation are for windshields mounted on the forebody of an airplane at several angles with the thrust axis. The flight operations were conducted in the Great Lakes region of the United States under conditions of natural icing during the winter of 1946-47.

Special weather forecasting for the icing flights were provided by representatives of the United States Weather Bureau. The windshields used were provided by the Pittsburgh Plate Glass Company.

APPARATUS

A special airplane-forebody section incorporating seven windshield panels each 11 inches square was mounted on a four-engine bomber-type airplane (fig. 1). The windshield panels were installed at the following angles with the thrust axis (fig. 2):

Windshield panel	Angle (deg)
1, 7	45
2, 3, 5, 6	30
4	60

Windshield panels 1, 2, and 4 were the laminated type and were electrically heated (fig. 3). The remaining windshields were not heated. A typical windshield installation is shown in figure 3. Electric power was furnished to the test panels by an auxiliary power plant installed in the waist compartment of the airplane.

INSTRUMENTATION

Temperatures of the outside and inside surfaces of each windshield panel were recorded by thermocouples. Three thermocouples were installed on both the outside and inside surfaces of each panel. The thermocouples were located diagonally across the panel, one in the center and one $4\frac{3}{4}$ inches on either side of the center (fig. 3). The installation of the thermocouples on the outside did not disturb the aerodynamic smoothness of the surface. The inside thermocouples were cemented to the surface with rubber cement. A shielded resistance-bulb thermometer was installed on the bottom of the airplane fuselage to measure ambient-air temperature.

Pressures at altitude and airspeed were measured by flush static orifices and a total-pressure tube located on the side of the airplane at the pilot's station.

The power furnished to the windshields was controlled by the use of wide-range variable transformers in each supply line and was measured by voltmeters and ammeters.

A rotating cylinder assembly, similar to that described in reference 2, was used to determine average droplet size, droplet-size distribution, and liquid-water content. The four cylinders used were $\frac{1}{8}$ inch, $\frac{1}{2}$ inch, $1\frac{1}{4}$ inches, and 3 inches in diameter.

A rotating disk-type icing rate meter was used to measure the icing rate. The principle of operation of this meter is given in reference 2.

RESULTS AND DISCUSSION

The results of this investigation are presented in table I and figure 4.

The quantity of heat provided for the 60° windshield is presumably an indication of the maximum that may be required for any configuration at the conditions experienced during this investigation (fig. 4(c)). The nature of the ice formation on the 60° windshield (fig. 5) indicates that a region of stagnation existed on the windshield. Convective heat transfer and the heat lost to the intercepted water is usually larger in the vicinity of a stagnation pressure region than in other regions of an aerodynamic body.

If a design condition is used that presumes a temperature rise of the windshield surface of 32° F above a 0° F ambient-air temperature, the conclusion may be made from the data in figure 4(c) that approximately 1300 Btu per hour per square foot will prevent ice formation at velocities up to 220 miles per hour and liquid-water content as large as 0.30 gram per cubic meter. Because of the high collection of liquid water, which was apparent on the 60° windshield, it is possible that the provision of 1300 Btu per hour per square foot will provide protection for the full range of water-droplet sizes that may be encountered under the conditions noted.

From data on the temperature rise of the various windshield surfaces, it has been ascertained that as the angle of the windshield with the thrust axis is decreased from 60° to 45°, the heat required remains constant. However, when the angle is decreased to 30°, about 25 percent less heat is required.

The ranges in airplane velocity and intensity of icing conditions were inadequate to permit a general statement of the relation between heat required for ice prevention and the operating conditions.

Observations made during the conduction of this research indicated that the use of electrically heated panels did not provide any protection for the windshield frame (fig. 6), whereas the air-heated airplane service installation (fig. 7) did provide frame protection. The center windshield of the airplane service installation was not heated.

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Cleveland, Ohio.

REFERENCES

1. Rodert, Lewis A., Clousing, Lawrence A., and McAvoy, William H.: Recent Flight Research on Ice Prevention, NACA ARR, Jan. 1942.

2. Vonnegut, B., Cunningham, R. M., and Katz, R. E.: Instruments for Measuring Atmospheric Factors Related to Ice Formation on Airplanes. Dept. Meteorology, De-Icing Res. Lab., M.I.T., April 1946. (Available from Office of Technical Services, U.S. Department of Commerce, as PB No. 48074.)

TABLE I

RESULTS OF FLIGHT INVESTIGATION TO DETERMINE THE TEMPERATURE RISE OF THE OUTSIDE SURFACE OF WINDSHIELDS ABOVE AMBIENT-AIR TEMPERATURE IN NATURAL ICING CONDITIONS

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Angle (deg)	Altitude (ft)	Velocity (mph)	Ambient-air temperature (°F)	Windshield-compartment temperature (°F)	Average windshield temperature (°F)		Heat input (Btu/(hr)(sq ft)	Average droplet size (microns)	Droplet-size distribution[a]	Liquid-water content (g/cu m)	Rate of icing (in./hr)
					Inside surface	Outside surface					
30	3310	177	13	25	40	26	499	8.7	A	0.365	2.64
45					34	23	408				
60					30	21	246				
30	3210	177	15	23	63	38	780	8.6	A	0.240	2.64
45					49	30	693				
60					44	27	558				
45	3310	180	15	24	60	37	983	8.5	A	0.280	1.68
60					54	31	809				
45	3310	177	14	24	78	45	1328	9.1	A	0.183	----
60					68	38	1093				
45	3310	177	15	24	79	45	1328	8.7	A	0.305	----
60					87	52	1419				
30	3210	157	16	23	49	31	493	8.5	A	0.275	----
45					61	38	976				
60					89	51	1410				
30	2820	152	26	35	90	58	859	11.0	E	0.202	1.13
45					95	62	1328				
60					99	62	1385				
30	2820	158	28	34	76	51	616	10.4	E	0.193	1.51
45					83	55	976				
60					88	57	1077				
30	3505	156	26	33	56	40	413	----	----	-----	0.56
45					62	44	988				
60					70	46	813				
30	3985	155	24	32	43	32	239	10.0	E	0.505	1.62
45					57	35	430				
60					59	42	565				
30	3405	162	25	31	36	31	119	7.9	E	0.330	0.38
45					40	33	274				
60					46	36	328				
30	9910	220	19	36	78	50	787	18.1	E	0.300	----
45					65	41	676				
60					68	41	795				
30	9710	225	19	35	60	40	495	18.0	E	0.240	----
45					51	44	444				
60					54	36	558				
30	9910	214	20	35	47	32	276	17.7	E	0.170	----
45					42	30	250				
60					46	33	357				
30	9910	191	20	35	76	51	775	18.0	E	0.120	----
45					63	43	676				
60					83	48	1003				
60	5580	178	20	36	61	30	817	15.0	A	0.340	2.5
60	5375	181	21	32	48	30	498	13.0	A	0.147	2.0
60	5480	185	21	31	79	50	1189	14.0	A	0.190	0.75

[a]Distributions A and E are described in reference 2, pp. 4-12.

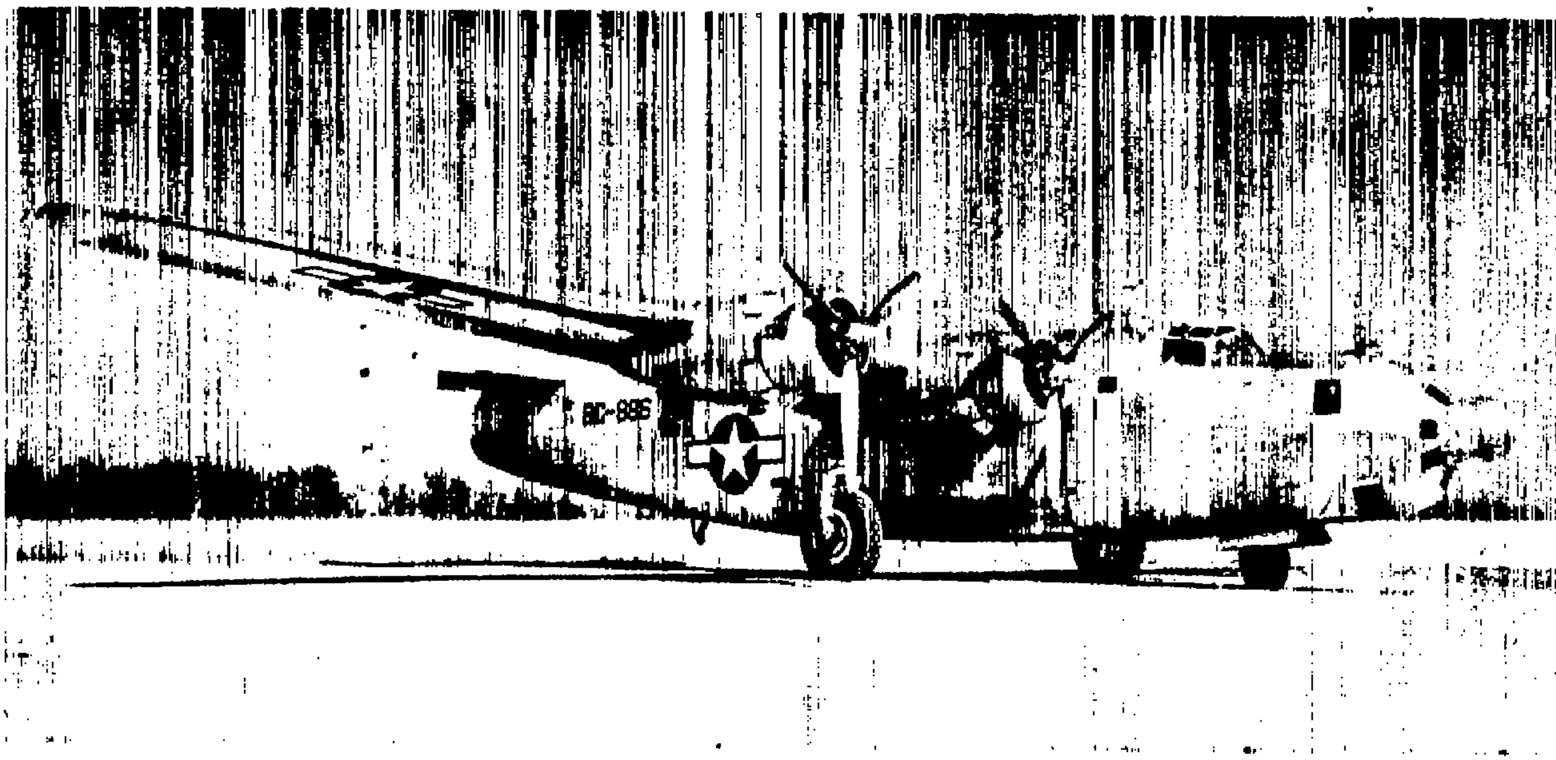

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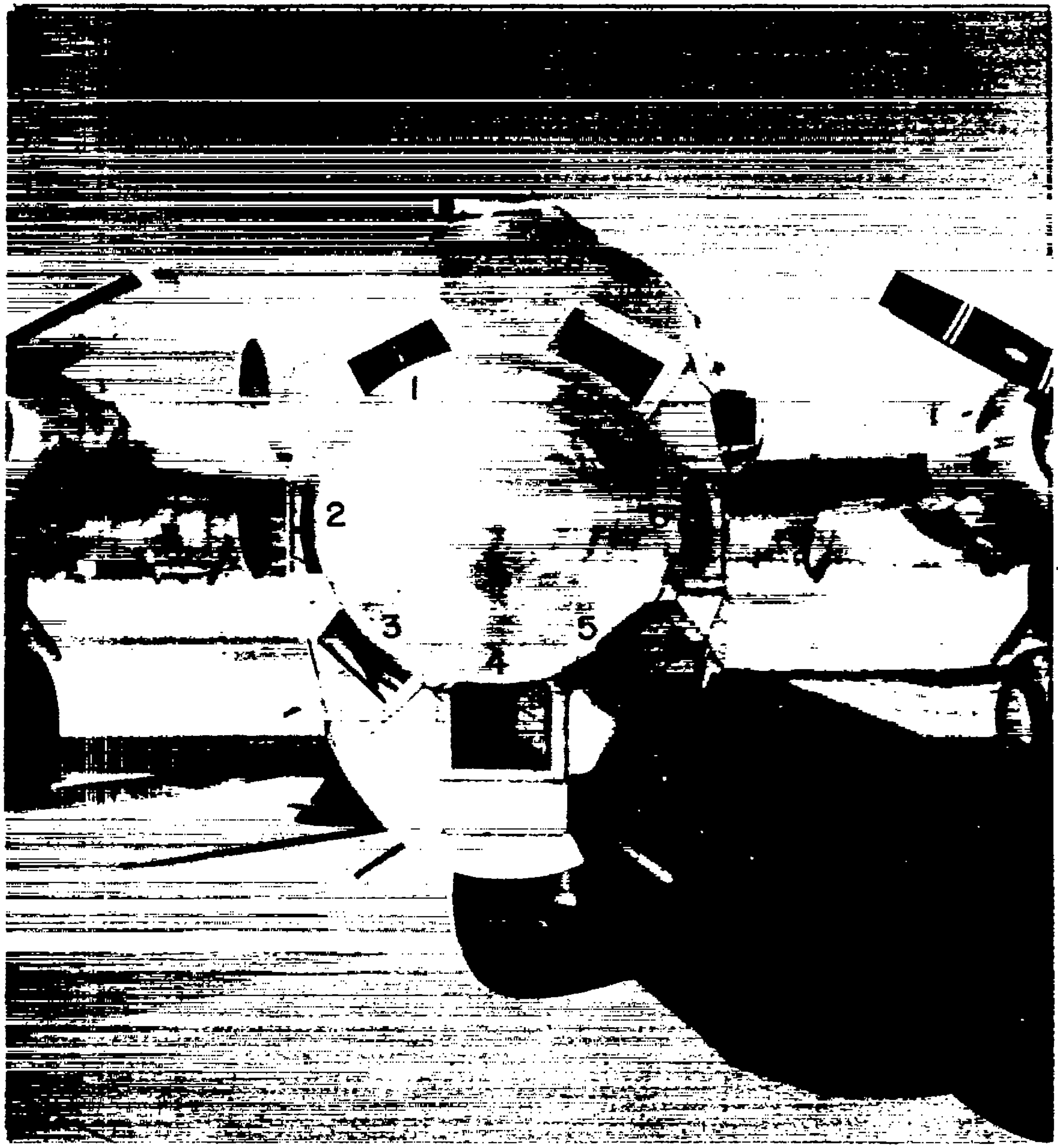
Figure 1. - Airplane with special windshield section mounted on forebody to determine heat required to prevent ice formation on aircraft windshields.



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(a) Front view.

Figure 2. - General arrangement of windshield panels for determining heat required to prevent ice formation on aircraft windshields.

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(b) Side view.

Figure 2. - Concluded. General arrangement of windshield panels for determining heat required to prevent ice formation on aircraft windshields.

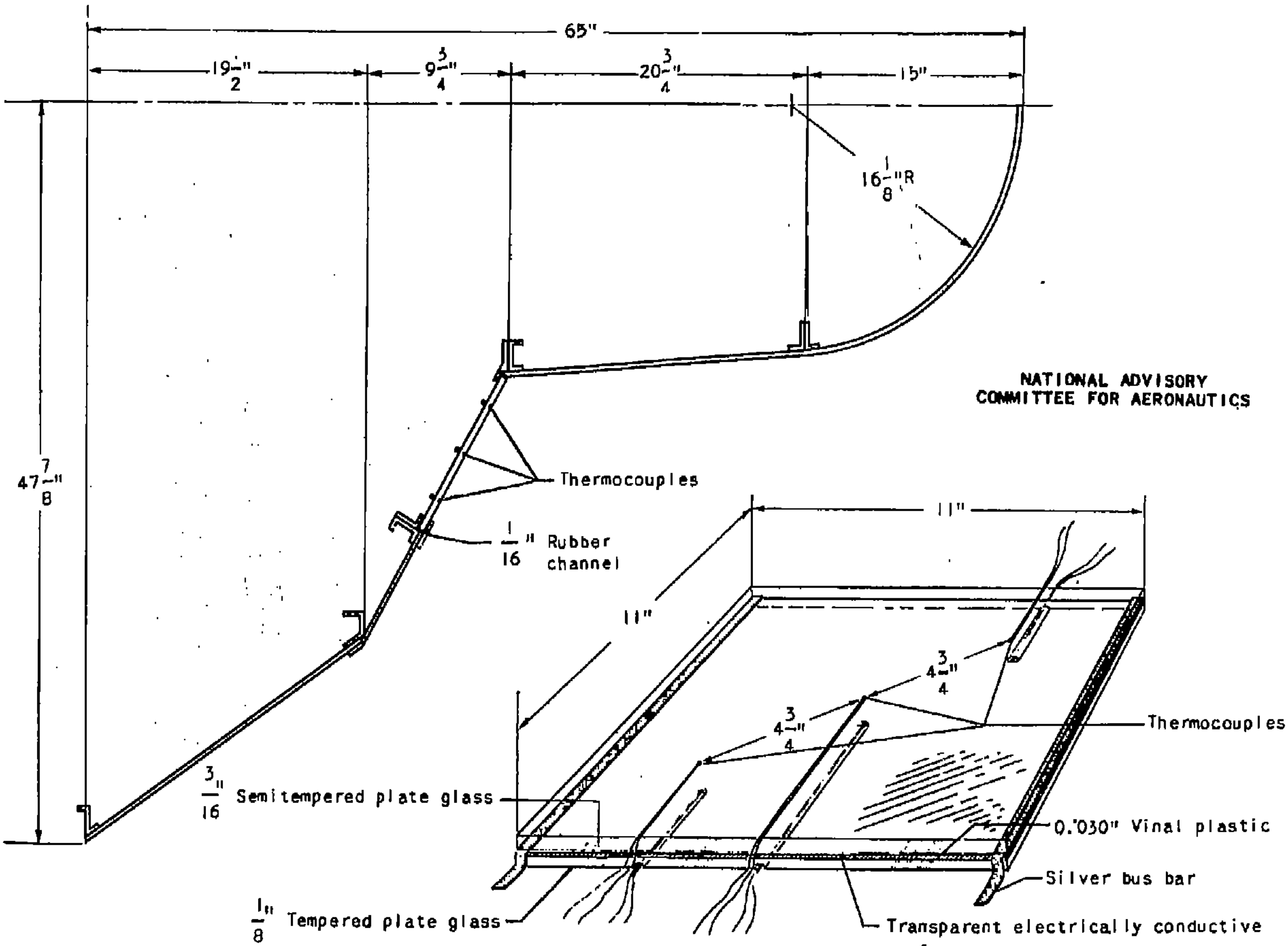

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Figure 3. - Typical windshield installation and details of windshield construction for determining heat required to prevent ice formation on aircraft windshields.

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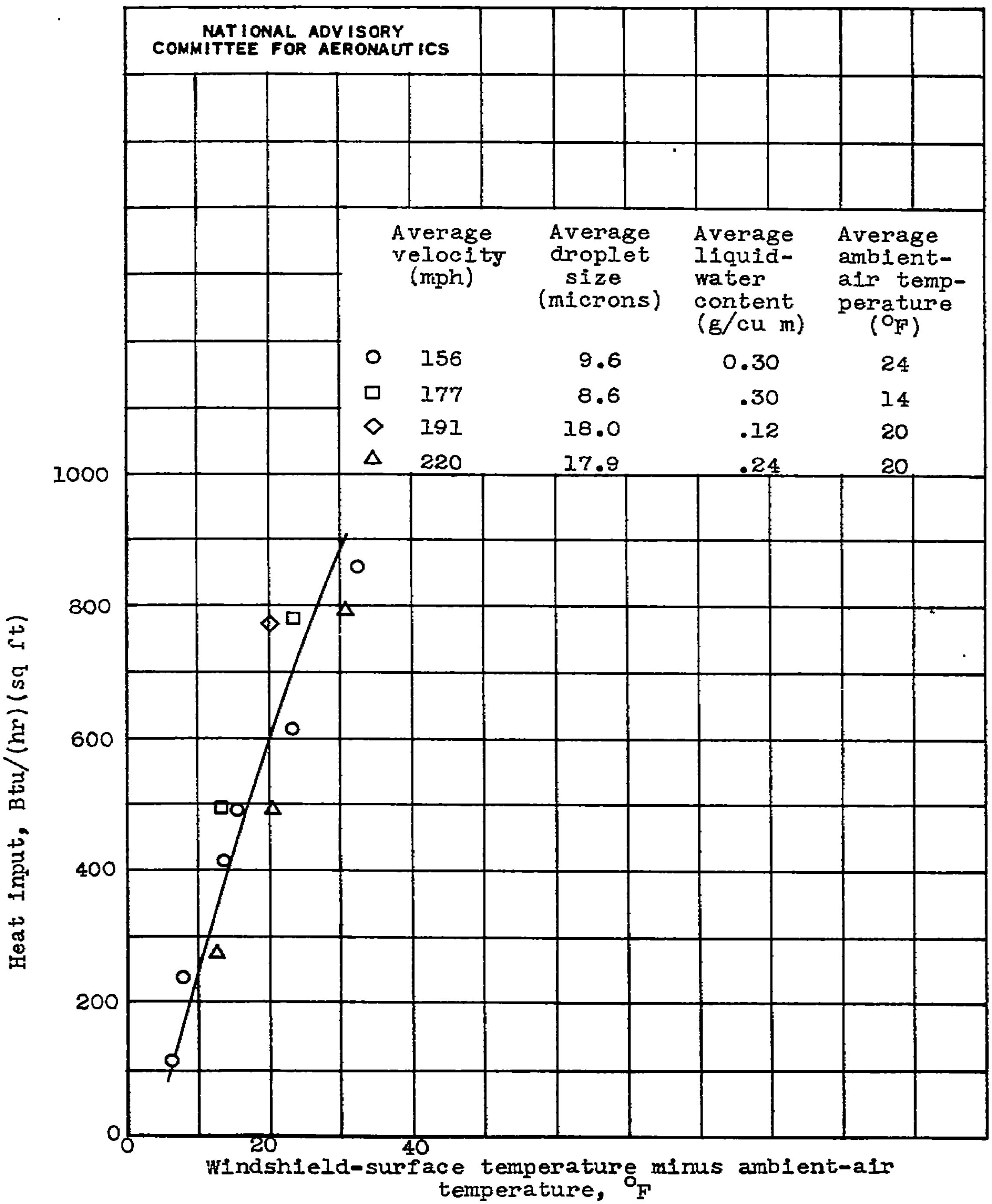
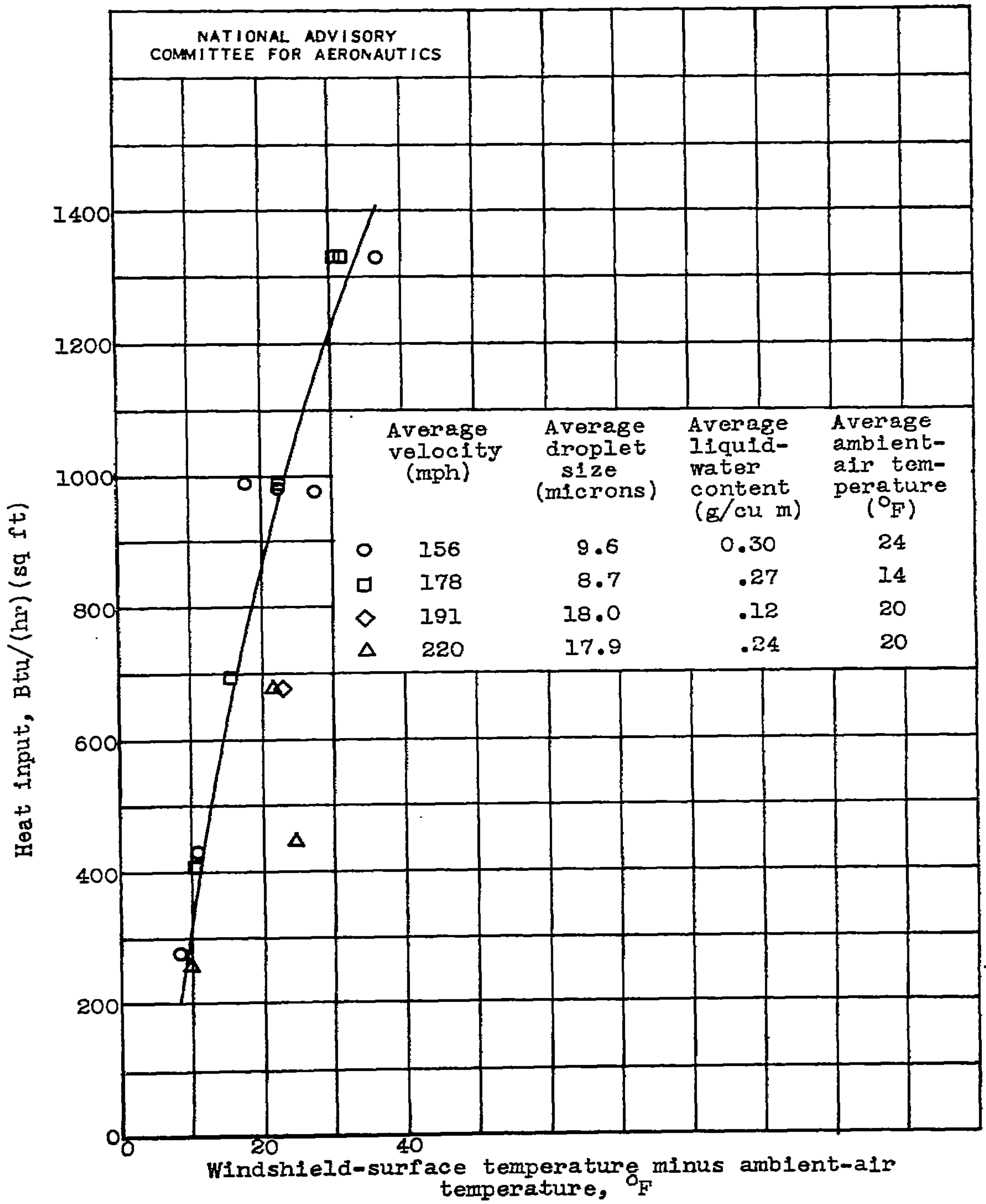


(a) Windshield angle with thrust axis, 30°.

Figure 4. - Variation of heat input with temperature rise of outside surface of windshield above ambient-air temperature.



(b) Windshield angle with thrust axis, 45°.

Figure 4. - Continued. Variation of heat input with temperature rise of outside surface of windshield above ambient-air temperature.

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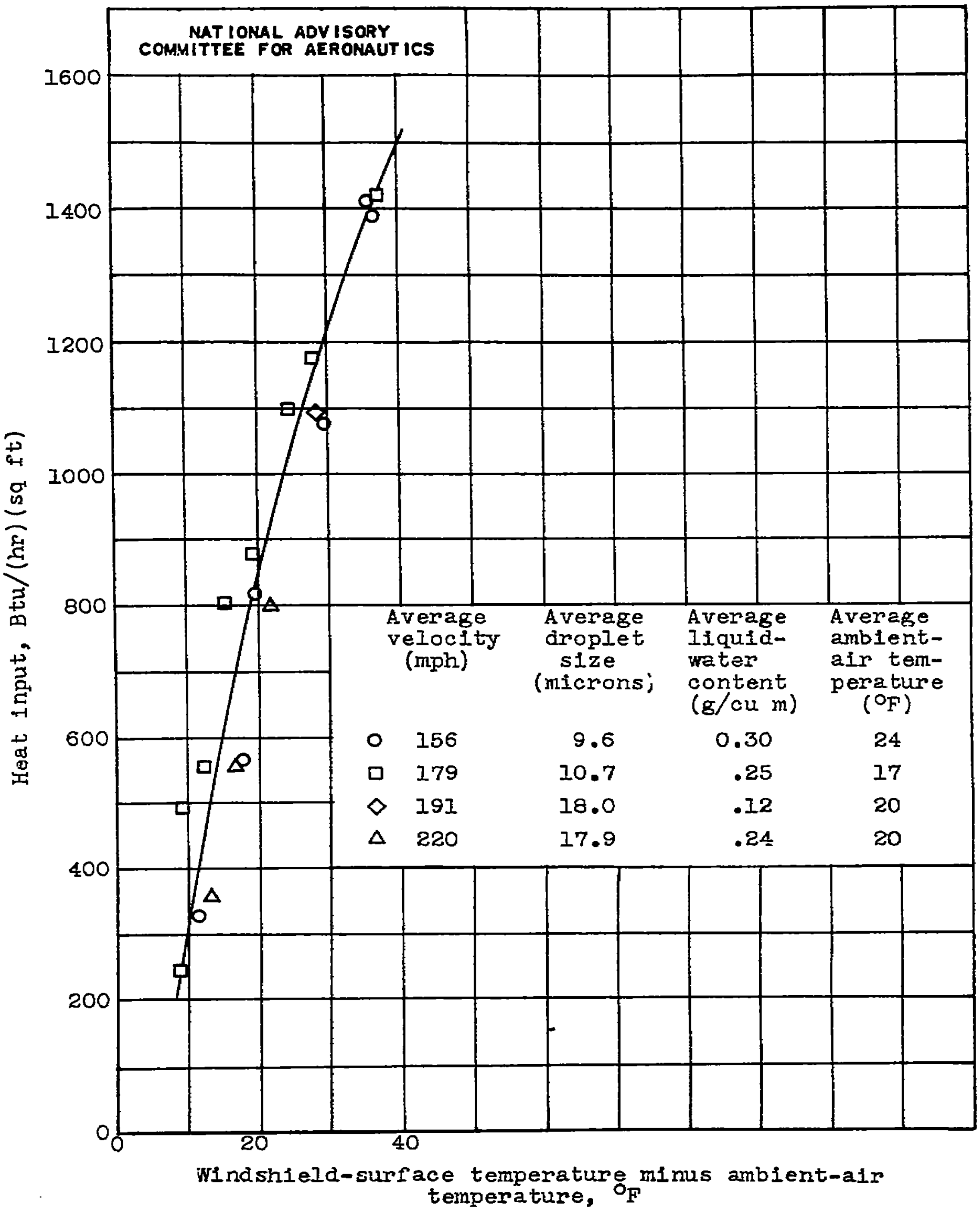

(c) Windshield angle with thrust axis, 60°.

Figure 4. - Concluded. Variation of heat input with temperature rise of outside surface of windshield above ambient-air temperature.

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Figure 5. - Ice formation on 60° windshield panel after flight with no heat applied.

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Figure 6. - Ice accretion on framework of 60° windshield during electrical thermal anti-icing of windshield.

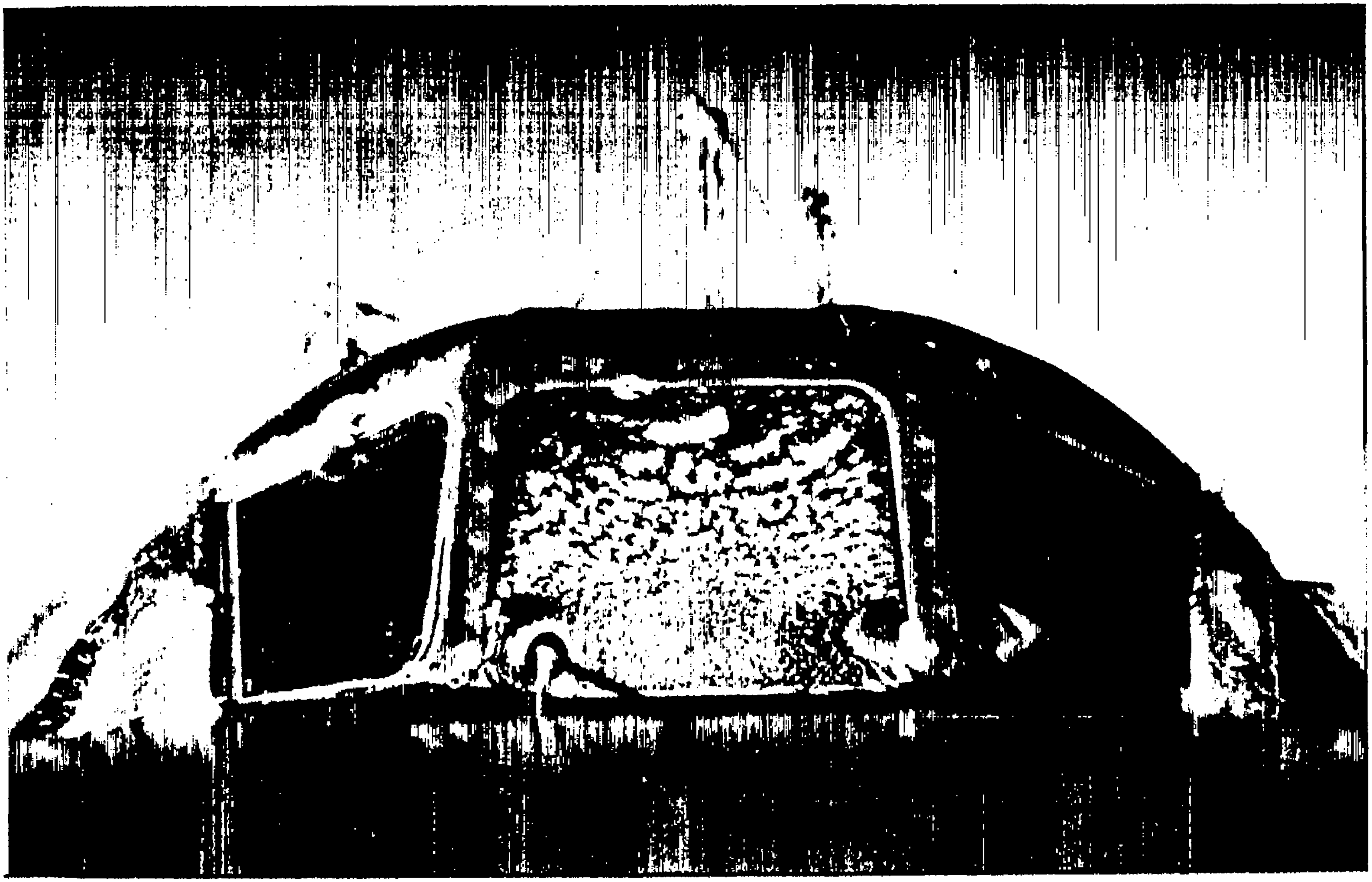

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Figure 7. - Airplane service windshields in natural icing condition. Thermal hot-air anti-icing on pilot's and copilot's windshields; center windshield not anti-iced.